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Original Article

Cephalometric appraisal of Class II treatment effects after functional and fixed appliances: a retrospective study

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Summary

Objective: To assess the dental, skeletal, and profile changes after functional appliances and subsequent fixed appliances treatment in order to quantify their effect and evaluate the influence of initial incisal inclination and growth pattern.

Materials and methods: A retrospective cephalometric analysis was performed in 125 patients (77 females and 48 males). Three lateral cephalograms per patient were available: before treatment (T0, mean age 11.9 years), after functional treatment (T1, mean age 12.9 years), and after fixed appliances (T2, mean age 14.8 years).

Results: At T1, a decrease of SNA (0.38° ± 0.77, $P < 0.05$), an increase of SNB (1.46° ± 0.66, $P < 0.05$), and a less convex profile (increase N′–Sn′–Pog′ of 2.93° ± 0.87, $P < 0.05$) were observed as compared to T0. The position of the upper incisors normalizes: initially retroclined upper incisors showed proclination and proclined incisors retroclination. At T1, proclination of the lower incisors was also noticed, being smaller the higher the initial I^NB. At T2, no significant changes in upper and lower incisor position were noticed compared to T1, as well as a decrease of the SNA (1.17° ± 0.75, $P < 0.001$) and SNB angles (0.41° ± 0.64, $P < 0.05$) and a stable profile convexity.

Conclusion: The improvement of the Class II relationship at T1 was mostly due to dentoalveolar changes: correction of the upper incisor position and proclination of the lower incisors. Skeletal changes were also noticed: constriction of maxillary growth combined with a growth stimulation of the mandible. At T2, no further proclination of the lower incisors was noticed.

Introduction

An angle Class II dentoskeletal disharmony is a frequently diagnosed malocclusion in orthodontic patients, mostly caused by mandibular retroposition (1). As a treatment modality, removable functional appliances are regularly used in growing patients (2). Correcting the jaw relationship and the overjet is the aim of this treatment (3–5). There appears to be an agreement in literature about the dentoalveolar effects of functional appliances (6–16): a combination of maxillary dental retraction and mandibular dental protrusion similar to the effects of interarch elastics. This 'Class II elastics effect' can be quite helpful in children who have maxillary dental protrusion and mandibular dental retroclination in combination with a Class II skeletal problem (Class II, 1 patient), but it is contraindicated in patients with maxillary dental retroclination or mandibular dental eversion (17). For this reason, a modification in design of the functional appliance is advised in Class II, 2 patients. Adding a bumper spring palatal to the upper incisors to create eversion of this teeth is helpful to avoid counteracting the mandibular advancement.

The skeletal effects, however, have long been discussed: alteration of maxillary growth, a possible change in the mandibular growth and position, and an improvement in the dental and muscular relationships have been suggested in literature (18). It has been said that the growth of the maxilla may be inhibited (19–21), redirected downward (22), or remains unaffected (23–25). The suggested growth restriction of the maxilla has been explained by the elasticity of the facial soft tissues, which would produce a reactive force against the maxilla when the mandible is held forward (17).

The reported mandibular effects of functional appliances are also contradictory: originally, it was thought that a functional appliance encouraged mandibular growth (26,27) because some authors have claimed that mandibular growth can be stimulated with functional treatment (6,28–31). However, others believe that mandibular length cannot be changed by these appliances (26,32). Growth modification has also been suggested for the mandible, described as 'posterior mandibular morphogenetic rotation', a biological mechanism leading to greater increments in total mandibular length by increasing the gonial angle (33,34). Nevertheless, more recent research explains the treatment results based on dentoalveolar effects and redirection of condylar growth (13,27,35,36). Additional growth is supposed to occur in response to the movement of the mandibular condyle out of the fossa, mediated by reduced pressure on the condylar tissues or by altered muscle tension on the condyle (17). Due to rotation of the mandible in a clockwise direction, the overbite decreases and the lower anterior face height increases. This is desirable in Class II patients having deep bite and reduced lower anterior face height, but not in patients with open bite and increased lower anterior face height (37). In these patients, more eruption of posterior teeth than growth of the ramus causes mandibular growth to be projected more downward than forward. In open growth pattern patients, further posterior eruption must be prevented to avoid growth being expressed entirely vertically (17).

The purpose of this research was to quantitatively investigate and compare, on lateral cephalograms, the dental, skeletal, and profile parameters before treatment (T0); after functional appliances (T1); and after continuation treatment with fixed appliances (T2). We also intended to evaluate whether parameters such as initial inclination of the upper incisors, initial inclination of the lower incisors, and initial growth pattern have an influence on the findings.

Materials and methods

This retrospective study was registered and approved by the Medical Ethics Committee of the University Hospitals Leuven, Leuven, Belgium (registration number S56533). The sample consisted of 125 Class II subjects (48 males and 77 females) who had undergone orthodontic treatment in the Department of Orthodontics of the University Hospitals Leuven. Almost 95 per cent of the sample were Caucasian patients with a mean age of 11.9 years (±1.64) and a Cervical Vertrebrae Maturation Stage (CVMS) of 2 or 3 (Table 1). Subjects treated with a removable functional appliance, followed by fixed appliances treatment, were selected. The sample was diagnosed with at least one half Class II molar relationship on both sides and an ANB angle of at least 4.5°. From these patients, three lateral cephalograms were available on three different time points: one before treatment (T0), one after functional appliance treatment (T1), and one after fixed appliances at the end of treatment (T2). No radiographic projections were taken only for the purpose of this study. Further inclusion criteria were no craniofacial disorder, orthodontic treatment without surgery, or extractions and good quality lateral cephalometric radiographs on all three occasions.

Table 1. Descriptive information. *n*, number; *N*, total number of patients; SD, standard deviation; IQR, interquartile range.

Variable	Statistic	All
Gender		
Male	*n*/*N* (%)	48/125 (38.40%)
Female	*n*/*N* (%)	77/125 (61.60%)
Age at T0	Mean; SD; IQR	11.9; 1.64; (10.8; 12.8)
Age at T1	Mean; SD; IQR	12.9; 1.55; (11.7; 14.0)
Age at T2	Mean; SD; IQR	14.8; 1.57; (13.7; 15.8)
CVMS (T0)		
1	*n*/*N* (%)	28/125 (22.40%)
2	*n*/*N* (%)	35/125 (28.00%)
3	*n*/*N* (%)	37/125 (29.60%)
4	*n*/*N* (%)	23/125 (18.40%)
5	*n*/*N* (%)	2/125 (1.60%)
Type of dentition		
Early mixed dentition	*n*/*N* (%)	16/125 (12.80%)
Late mixed dentition	*n*/*N* (%)	53/125 (42.40%)
Definitive dentition	*n*/*N* (%)	56/125 (44.80%)
Dental age (T0)	*N*	120
	Mean; SD; IQR	13.5; 1.45; (12.6; 14.5)
Type of functional appliance		
(Half-)Open activator	*n*/*N* (%)	51/125 (40.80%)
Bionator	*n*/*N* (%)	30/125 (24.00%)
Van Beek	*n*/*N* (%)	20/125 (16.00%)
Andresen	*n*/*N* (%)	19/125 (15.20%)
Other (Ducovator/ Twin-Block)	*n*/*N* (%)	5/125 (4.00%)
Interval T0–T1 (months)	Mean; SD; IQR	12.1; 6.04; (8.0; 15.0)
Interval T1–T2 (months)	Mean; SD; IQR	22.9; 8.17; (17.3; 27.2)
Interval T0–T2 (months)	Mean; SD; IQR	35.0; 9.07; (28.6; 39.6)
I^NA		
I^NA < 18°	*n*/*N* (%)	35/125 (28.00%)
18° ≤ I^NA ≥ 22°	*n*/*N* (%)	11/125 (8.80%)
I^NA > 22°	*n*/*N* (%)	79/125 (63.20%)
I^NB		
I^NB < 23°	*n*/*N* (%)	47/125 (37.60%)
23° ≤ I^NB ≥ 27°	*n*/*N* (%)	36/125 (28.80%)
I^NB > 27°	*n*/*N* (%)	42/125 (33.60%)
SN^GoMe		
SN^GoMe < 27°	*n*/*N* (%)	14/125 (11.20%)
27° ≤ SN^GoMe ≥ 37°	*n*/*N* (%)	95/125 (76.00%)
SN^GoMe ≥ 37°	*n*/*N* (%)	16/125 (12.80%)
ArGo^GoMe		
ArGo^GoMe < 116°	*n*/*N* (%)	18/125 (14.40%)
116° ≤ ArGo^GoMe ≥ 136°	*n*/*N* (%)	107/125 (85.60%)
ArGo^GoMe ≥ 136°	*n*/*N* (%)	0/125 (0.00%)

The appliances included in this study were all activators: Van Beek activator (38), Andresen activator (39,40), Half-Open activator with bumper spring, Open activator, Ducovator, Bionator (41), and Twin-Block (37). The type of activator was selected by the treating orthodontist based on a number of parameters, such as the initial position of upper and lower incisors. Patients were instructed to wear the appliance a minimum of 14 hours a day.

For this retrospective study, a part of the cephalometric radiographs were available in the archive of the Department of Orthodontics of the University Hospitals Leuven as analogue radiographs. The remainder was digitally available in the patient's file. Only headfilms adjusted for magnification were used.

The conventional cephalometric radiographs were taken with a Siemens Orthophos C (Sirona Dental, Bensheim, Germany) or a Cranex Tome (Soredex, Tuusala, Finland). An Epson Expression 1680 Pro flatbed scanner (Seiko Epson Corp., Nagano, Japan) was used for scanning the films, and digitizing was performed with Epson Twain scanning software (Seiko Epson Corp., Nagano, Japan). A Veraviewepocs 2D (J. Morita Co., Kyoto, Japan) was employed for making the direct-digital cephalometric radiographs. These three lateral headfilms were traced and landmarks were located using the Vistadent AT 3.1 software (GAC International, Bohemia, New York, USA).

A total of 48 cephalometric measurements (16 dental, 24 skeletal, and 8 profile) were performed on all radiographs. The cephalometric analysis performed in this study is a combination of the Steiner analysis (42), the method of Kinzinger *et al.* (43), and De Almeida *et al.* (18).

First, the results were analyzed in toto without any initial differentiation on any parameter at T0. Second, the results were subcategorized into three subgroups. The first subgroup was defined based on upper incisor inclination towards the NA line and further subdivided in three groups: I^NA lower than 18°, I^NA between 18° and 22°, and I^NA bigger than 22°. The second subgroup was differentiated based on lower incisor inclination towards the NB line, allowing for differentiation between patients with initially retroclined lower incisors (I^NB lower than 23°), initially proclined lower incisors (I^NB bigger than 27°), and initially normally inclined lower incisors (I^NB between 23° and 27°). The third subgroup was based on the mandibular growth pattern, expressed by SN^GoMe and ArGo^GoMe (gonial angle). Again a subdivision was made in three groups. SN^GoMe lower than 27° or ArGo^GoMe lower than 116° were considered as patients with closed growth pattern, SN^GoMe bigger than 37° or ArGo^GoMe bigger than 136° were considered as patients with an open growth pattern, and SN^GoMe between 27° and 37° and ArGo^GoMe between 116° and 136° were classified as normal growth pattern patients. The above-mentioned parameters with corresponding standard deviations were chosen according to Steiner and Jarabak norm values (42,44).

Possible correlations with gender, CVMS, type of dentition, chronological age, and dental age were also explored. The CVMS of all patients was determined at T0 according to the method of Baccetti *et al.* (45), while the dental age assessment at T0 was performed in those patients who had a panoramic radiograph available in their file (120 of 125 patients). The seven left permanent teeth of the mandible were given a maturity score in years and were summed to obtain a dental age using the method of Willems *et al.* (46).

Statistical analysis

A linear model for longitudinal measures was used to evaluate the changes over time for each measurement separately. The variance and the correlation between the three time points were modelled with an unstructured covariance matrix. P values with Tukey adjustments were used for pairwise comparisons between time points.

Changes between T0 and T1 and between T1 and T2 were compared between groups (gender, type of appliance, dental development phase, and dental age) using an analysis of variance (ANOVA), again using Tukey adjustments for pairwise comparison. Spearman correlations were used to evaluate the relations with continuous (age at T0) and ordinal variables (CVMS). For each analysis, P values corrected for multiple testing (Bonferroni–Holm correction) over the 48 outcomes were reported. Intra-class correlations (ICCs) and standard error of measurements (SEM) were calculated for the intra- and inter-observer reliability. Changes between the levels of grouping were evaluated with ANOVA comparing the changes between the different groups. P values with Tukey–Kramer correction were used. Again the P values were corrected for multiple testing, using a Bonferroni–Holm correction.

All analyses have been performed using SAS software, version 9.2 of the SAS System for Windows.

To determine the intra- and inter-observer variability of the measurements, a group of 90 radiographs were traced twice by two observers (AZ and MC) at an interval of at least 2 weeks, blinded to each other's measurements.

Results

The descriptive statistics are reported in Table 1 and cephalometric parameters in Table 2.

Assessment of measurement error

For most of the measurements, the intra-observer ICC was higher than 0.90 and the inter-observer ICC was higher than 0.85. The only exception was the measurement Go–FHP, where the intra-observer ICC was 0.394 and the inter-observer ICC was 0.509.

Dental changes

The upper incisor tended to retrude on average 0.56 mm (SD 0.4, $P = 0.019$) and 2.02° towards the NA line (SD 1.17, $P = 0.008$) at T1. At T2, however, it became more protruded again (2.14°, SD 1.02, $P < 0.001$), which resulted in a final normal inclination.

The lower incisor tended to procline on average 1.46 mm (SD 0.35, $P < 0.001$) and it became on average 5.4° more proclined towards the NB line (SD 1.08, $P < 0.001$) at T1. Also towards the mandibular plane (GoGn), the lower incisor became on average 4.3° more proclined (SD 1.27, $P < 0.001$). At T2, the inclination of the lower incisor remained unchanged compared with T1.

Towards the FHP line, the upper molar and upper incisor remained approximately at the same place at T1. The lower incisor and molar were positioned more ventrally at T1 ($P < 0.001$). The lower molar mesialised even more from the FHP line at T2 (1.6 mm, SD 0.93, $P < 0.001$).

Skeletal changes

The SNA angle decreased 0.38° (SD 0.77, $P = 0.031$) at T1 and 1.17° (SD 0.75, $P < 0.001$) at T2. The mandible grew in all its dimensions with increases at T1 being at least twice as big compared with T2: the total length of the mandible increased 5.43 mm at T1 (Co–Gn, SD 1.1, $P < 0.001$) and 2.19 mm at T2 (SD 1.16, $P < 0.001$), the ramus length increased 3.47 mm (Ar–Go, SD 0.86, $P < 0.001$) at T1 and 1.25 mm (SD 0.88, $P < 0.001$) at T2, and the lower border increased 2.35 mm (Go–Me, SD 0.86, $P < 0.001$) at T1 and 1.82 mm (SD 0.83, $P < 0.001$) at T2.

Towards the FHP line, the chin (Pog–FHP, SD 1.28, $P < 0.001$) and lower jaw moved 3.2 mm and 3.01 mm forward (B–FHP 3.01 mm, SD 1.14, $P < 0.001$) at T1, respectively. At T2, these measurements remained approximately the same.

The SNB angle increased 1.46° (SD 0.66, $P < 0.001$) at T1 and then decreased again at T2 with 0.41° (SD 0.64, $P = 0.007$). The overjet diminished 4.74 mm (SD 0.26, $P < 0.001$) at T1 and another 0.44 mm (SD 0.17, $P = 0.010$) at T2.

Table 2. Evaluation of the cephalometric general changes over time. Mean values with standard deviation are listed with T0, before treatment; T1, after functional appliance; T2, after fixed appliances. *P* values were based on analysis of variance, using Tukey adjustments for pairwise comparisons. The values of $P < 0.005$ are indicated in bold and that of $P < 0.05$ are indicated in italics.

Variable	T0	T1	T2	*P* value	T0–T1	T1–T2	T0–T2
I–NA (mm)	5.47 ± 0.44	4.91 ± 0.40	4.70 ± 0.40	0.003	*0.019*	0.548	0.003
I^NA (°)	23.96 ± 1.55	21.94 ± 1.17	24.08 ± 1.01	<0.001	0.008	<0.001	0.990
I–NB (mm)	4.82 ± 0.32	6.28 ± 0.35	5.95 ± 0.31	<0.001	<0.001	*0.038*	<0.001
I^NB (°)	24.83 ± 1.03	30.23 ± 1.08	30.47 ± 0.92	<0.001	<0.001	0.898	<0.001
U6^ANSPNS (°)	78.95 ± 0.92	77.33 ± 1.04	82.71 ± 0.94	<0.001	0.003	<0.001	<0.001
U6–ANSPNS (mm)	19.07 ± 0.36	19.91 ± 0.39	21.07 ± 0.38	<0.001	<0.001	<0.001	<0.001
U1^ANSPNS (°)	111.84 ± 1.48	109.64 ± 1.02	111.00 ± 0.92	<0.001	0.003	*0.016*	0.544
U1–ANSPNS (mm)	26.10 ± 0.42	26.83 ± 0.43	27.32 ± 0.45	<0.001	<0.001	<0.001	<0.001
L6^GoGn (°)	88.55 ± 0.83	88.36 ± 0.90	84.66 ± 0.82	<0.001	0.896	<0.001	<0.001
L6–GoGn (mm)	24.68 ± 0.43	25.89 ± 0.43	27.54 ± 0.47	<0.001	<0.001	<0.001	<0.001
L1^GoGn (°)	99.27 ± 1.11	103.57 ± 1.27	104.05 ± 1.18	<0.001	<0.001	0.666	<0.001
L1–GoGn (mm)	33.65 ± 0.45	33.98 ± 0.46	34.18 ± 0.54	0.004	*0.036*	0.458	0.007
FHP–U6 (mm)	40.55 ± 0.82	40.72 ± 0.87	42.98 ± 0.90	<0.001	0.813	<0.001	<0.001
FHP–U1 (mm)	72.35 ± 1.01	72.38 ± 1.01	72.21 ± 0.95	0.872	0.996	0.878	0.912
FHP–L6 (mm)	38.57 ± 0.88	43.05 ± 0.93	44.71 ± 0.93	<0.001	<0.001	<0.001	<0.001
FHP–L1 (mm)	64.99 ± 0.98	69.36 ± 0.96	69.58 ± 0.92	<0.001	<0.001	0.777	<0.001
Co–A (mm)	80.93 ± 0.90	82.26 ± 1.00	82.90 ± 0.94	<0.001	<0.001	0.180	<0.001
A–FHP (mm)	66.99 ± 0.78	67.75 ± 0.85	67.79 ± 0.81	<0.001	0.004	0.987	0.002
Ar–Go (mm)	40.64 ± 0.73	44.11 ± 0.86	45.36 ± 0.88	<0.001	<0.001	<0.001	<0.001
Co–Gn (mm)	100.48 ± 1.05	105.91 ± 1.10	108.10 ± 1.15	<0.001	<0.001	<0.001	<0.001
B–FHP (mm)	59.51 ± 1.03	62.61 ± 1.14	63.08 ± 1.14	<0.001	<0.001	0.358	<0.001
Go–Me (mm)	65.54 ± 0.81	67.89 ± 0.86	69.71 ± 0.83	<0.001	<0.001	<0.001	<0.001
Pog–FHP (mm)	60.82 ± 1.20	64.02 ± 1.28	64.65 ± 1.28	<0.001	<0.001	0.264	<0.001
Go–FHP (mm)	4.09 ± 0.90	4.08 ± 0.76	4.88 ± 0.77	*0.042*	0.999	0.072	0.136
Go–Pog (mm)	68.48 ± 0.83	70.72 ± 0.88	72.62 ± 0.84	<0.001	<0.001	<0.001	<0.001
SN^ANSPNS (°)	6.01 ± 0.59	6.04 ± 0.62	6.55 ± 0.63	0.004	0.983	*0.010*	*0.012*
SN^GoMe (°)	32.40 ± 0.85	32.15 ± 0.91	32.31 ± 0.95	0.342	0.373	0.627	0.915
ArGo^GoMe (°)	121.98 ± 1.02	122.73 ± 1.03	121.46 ± 1.14	<0.001	0.004	<0.001	0.125
SNA (°)	81.87 ± 0.69	81.49 ± 0.77	80.32 ± 0.75	<0.001	*0.031*	<0.001	<0.001
SNB (°)	76.01 ± 0.60	77.47 ± 0.66	77.06 ± 0.64	<0.001	<0.001	0.007	<0.001
ANB (°)	5.86 ± 0.38	4.02 ± 0.43	3.26 ± 0.39	<0.001	<0.001	<0.001	<0.001
OJ (mm)	7.99 ± 0.45	3.25 ± 0.26	2.81 ± 0.17	<0.001	<0.001	0.010	<0.001
Wits	3.51 ± 0.41	0.98 ± 0.48	0.89 ± 0.43	<0.001	<0.001	0.908	<0.001
S–Go (mm)	69.37 ± 0.94	73.30 ± 0.84	75.66 ± 1.11	<0.001	<0.001	<0.001	<0.001
N–Pog (mm)	97.75 ± 1.07	102.18 ± 1.12	105.16 ± 1.20	<0.001	<0.001	<0.001	<0.001
N–Me (mm)	104.55 ± 1.07	109.00 ± 1.15	112.18 ± 1.24	<0.001	<0.001	<0.001	<0.001
ANS–Me (mm)	59.67 ± 0.78	62.32 ± 0.84	64.07 ± 0.91	<0.001	<0.001	<0.001	<0.001
N–A (mm)	51.14 ± 0.57	52.59 ± 0.64	54.57 ± 0.64	<0.001	<0.001	<0.001	<0.001
N–B (mm)	86.59 ± 0.96	90.89 ± 1.03	93.25 ± 1.06	<0.001	<0.001	<0.001	<0.001
N–ANS (mm)	46.84 ± 0.59	48.06 ± 0.62	49.50 ± 0.62	<0.001	<0.001	<0.001	<0.001
N′Ns ′^Ns′Pog ′ (°)	125.41 ± 0.77	126.32 ± 0.79	125.09 ± 0.71	<0.001	0.001	<0.001	0.392
N′Sn ′^Sn′Pog′ (°)	155.16 ± 0.86	158.09 ± 0.87	157.72 ± 0.84	<0.001	<0.001	0.458	<0.001
NLA (°)	113.51 ± 1.69	113.39 ± 1.58	114.74 ± 1.67	0.069	0.979	0.076	0.155
FHP–upper lip (mm)	82.84 ± 0.96	83.94 ± 1.09	84.81 ± 1.07	<0.001	0.003	*0.042*	<0.001
FHP–lower lip (mm)	78.28 ± 1.04	81.49 ± 1.13	82.21 ± 1.08	<0.001	<0.001	0.123	<0.001
Upper lip–E line (mm)	−0.14 ± 0.40	−2.39 ± 0.43	−3.26 ± 0.40	<0.001	<0.001	<0.001	<0.001
Lower lip–E line (mm)	−0.07 ± 0.46	−0.61 ± 0.48	−1.34 ± 0.44	<0.001	0.003	<0.001	<0.001
Sn′–Me′ (mm)	60.54 ± 0.85	63.13 ± 0.85	64.78 ± 0.94	<0.001	<0.001	<0.001	<0.001

The upper anterior face height (N–ANS) increased on average 1.22 mm (SD 0.46, $P < 0.001$) at T1 and 1.44 mm at T2 (SD 0.62, $P < 0.001$).

The lower anterior face height (ANS–Me) also increased at T1 (2.65mm, SD 0.84, $P < 0.001$) and T2 (1.75mm, SD 0.91, $P < 0.001$). The posterior face height (S–Go) increased on average 3.93 (SD 1.04) and 2.36 mm (SD 1.12) at T1 and T2, respectively ($P < 0.001$). The distance between point N and points Pog, Me and B increased on average 4.43 (SD 1.13), 4.45 (SD 1.15), and 4.3 (SD 1.03) mm, respectively, at T1 ($P < 0.001$) and 2.98 (SD1.2), 3.18 (SD 1.24) and 2.36 (SD 1.06) mm, respectively, at T2 ($P < 0.001$).

The biggest change of the Wits appraisal was seen between T0 (3.51 mm, SD 0.41) and T1 (0.98 mm, SD 0.48, $P < 0.001$), while at T2 (0.89 mm, SD 0.44, $P = 0.908$), no significant changes were noticed.

Profile changes

At T1, the angle of convexity of the profile—with the nose excluded—tended to become less convex (increase of the N′–Sn′–Pog′ angle an average of 2.93°, SD 0.87, $P < 0.001$), and at T2, no statistically significant change in this angle was observed (decrease of 0.37°, SD 0.84, $P = 0.458$). The distance from the FHP line towards the upper and lower lip increased with 1.1 (SDD 1.1, $P < 0.003$) and 3.21 mm (SDD 1.13, $P < 0.001$) respectively at T1. Their positions remained stable at T2.

Towards the esthetic line (E line), the upper lip went more dorsally: on average 2.25 mm at T1 (SD 0.43, $P < 0.001$) and 0.87 mm at T2 (SD 0.41, $P < 0.001$). The lower lip also moved dorsally towards the esthetic line: 0.54 mm at T1 (SD 0.48, $P = 0.003$) and 0.73 mm at T2 (SD 0.45, $P < 0.001$). The nasolabial angle remained stable after both phases of treatment.

The lower anterior face height (Sn′–Me′) increased the most at T1 (2.59 mm, SD 0.85, $P < 0.001$) and then increased 1.65 mm more at T2 (SD 0.95, $P < 0.001$).

Categorization of results based on three different approaches

First, the results were differentiated based on the I^NA measurement. For all 48 measurements, there were only 2 parameters showing statistically significantly different results. The first one was the angulation of the upper incisors. In the retroclined group, the upper incisor proclined 4.64° at T1 ($P < 0.001$), going from 12.64° at T0 to 17.28° at T1. In the eversion group, the upper incisor retroclined 5.34° ($P < 0.001$), going from 29.49° at T0 to 24.15° at T1. The second measurement was the overjet. The biggest decrease in overjet at T1 was seen in the eversion group (−5.44 mm), while the smallest reduction was noticed in the retroinclined group (−3.17 mm).

Second, the results were differentiated based on the initial position of the lower incisor. In the lower incisor retroclination group, 7° proclination was seen. In the normal position group, 5° proclination was noticed. And in the initially proclination lower incisor group, 3.8° proclination was seen at T1. In all groups, lower incisor inclination towards the NB line ended up around 30°.

Third, a distinction was made based on the analysed growth pattern (SN^GoMe angle and ArGo^GoMe angle). Interestingly, no statistical significant differences were found in treatment results when grouped according to the initial growth pattern. The face height dimensions were similar for all groups both at T1 and T2.

Correlations between results and possibly influencing factors

No significant differences in treatment results according to gender, type of dentition (ranging from early mixed to definitive), dental age, or type of activator were found in the present study (Table 3).

When it comes to the CVMS, our results suggest that the higher the stage at T0, the smaller the skeletal changes were at T2, i.e. the total length and length of the lower border of the mandible and the posterior and anterior face height showed a negative correlation coefficient.

No significant differences in treatment results at T1 were seen depending on the chronological age at T0. At T2, however, some skeletal measurements were negatively correlated with a higher chronological age at T0: the length of the lower border of the mandible, the upper anterior, and the total anterior face height.

Discussion

The purpose of this study was to investigate which changes can be expected after functional appliances and subsequent fixed appliances treatment and whether these results were different depending on the original position of the upper and lower incisor and initial growth pattern.

To begin with, it needs to be considered that confounding factors such as the study design, the measurement error, and the influence of natural growth might have influenced the results obtained. In addition, the retrospective nature and the different operators in training at the Department of Orthodontics of the University Hospitals Leuven will certainly have had an impact on treatment results.

Also, for some cephalometric variables, the range described for the SEM is quite big. Deeper analysis of this wide range indicates that the highest SEM values were found for measurements including constructed cephalometric points, e.g. Go. The SEM for these measurements was systematically higher. This suggests that reference points placed on anatomical landmarks are relatively easy to identify, whereas those placed on curves with wide radii show greater measurement errors (47).

We also reported results with, at first sight, little significant changes, which could raise the question whether they are clinically relevant. In this context, Kamoen *et al.* (48) reported a list of critical values from which on the observed differences would result in clinically relevant changes: SNA (0.4°), SNB (0.3°), ANB (0.2°), I^NA (0.7°), I–NA (0.5mm), I–NB (0.4mm), and L1^GoGn (1.0°). With this in mind, it was found that all the present results may be interpreted as clinically relevant.

To be able to critically analyse some of our results, and to isolate the influence of natural growth, a comparison was made with the data reported by Flores-Mir *et al.* in their 2009 article (49). They studied an untreated, age-matched Class II control group of 30 patients (20 boys and 10 girls). The group differences between this control group and our study group suggest that the Class II correction in our treatment group is mostly obtained by restricting maxillary growth (decrease of 1.28° in the SNA angle). The contribution of mandibular skeletal advancement is in contrast rather small (increase of 0.46° in the SNB angle). The ANB angle decreased 1.64° more in our study group. Compared to these non-treated Class II subjects, a 4.34 mm larger overjet reduction was found in the present study. Also a remarkable eversion of the lower front teeth seemed to contribute to the correction of this malocclusion (L1–MP increases 3.2°).

What concerns the dental changes observed in the present study, it was noticed that the upper incisors were in a normal position at T1, compared with the norm values described by Steiner (42), while at T0, they were too much protruded (Table 2). However, the values described in Table 2 are mean values, reason why the subcategorization of the results for the three reported subgroups was especially interesting. When the upper incisors were initially retroclined, proclination was noticed, while in the proclination group retroclination was seen, concluding that the position of the upper incisor was normalizing for both groups.

Another important clinical factor is the original position of the lower incisor. Our results suggest that patients with initially proclined lower incisors should not be directly excluded from functional appliance treatment, because the amount of labial inclination observed in this group was significantly lower at T1 compared with the other two subgroups. All three subgroups ended up with higher proclination at T1, compared with the 25° prescribed by Steiner (42). Interestingly, no correction of this labial inclination was obtained after fixed appliances treatment. Possible ways to do this could be using lower incisor brackets with negative torque values or bending buccal root torque in the anterior segment of the archwire. Since additionally the use of Class II elastics was regularly seen in our patients' files, this could also be a reason why proclination of the lower front teeth at T2 was not significantly corrected, together with the fact that treatment was carried

Table 3. Evaluation of treatment changes for the different functional appliances at T1. *P* values were based on analysis of variance, using Tukey adjustments for pairwise comparisons. *P* values corrected for multiple testing (Bonferroni–Holm correction) reported by Adj *P*. The values of $P < 0.005$ are indicated in bold and that of $P < 0.05$ are indicated in italics.

	Change T0–T1						
Variable	(Half-) Open activator	Bionator	Van Beek	Andresen	Other (ducovator/ Twin-Block)	P-value	Adj P
I–NA (mm)	0.14	−0.73	−1.50	−1.32	0.00	*0.027*	0.989
I^NA (°)	0.20	−3.30	−4.43	−4.16	1.84	*0.031*	1.000
I–NB (mm)	1.60	1.70	0.60	1.58	1.80	*0.018*	0.719
I^NB (°)	5.58	6.26	2.39	6.05	8.56	*0.009*	0.397
U6^ANSPNS (°)	−2.12	0.79	−4.06	−1.79	−0.72	*0.027*	0.989
U6–ANSPNS (mm)	0.95	0.96	0.53	0.81	0.36	0.804	1.000
U1^ANSPNS (°)	−0.10	−3.15	−5.76	−3.65	1.88	*0.015*	0.615
U1–ANSPNS (mm)	1.07	0.95	−0.24	0.58	0.56	0.052	1.000
L6^GoGn (°)	0.89	−0.09	−2.80	−0.50	−0.42	0.088	1.000
L6–GoGn (mm)	1.15	1.23	0.94	1.23	2.88	0.178	1.000
L1^GoGn (°)	4.63	4.99	1.08	4.77	7.92	*0.006*	0.280
L1–GoGn (mm)	0.23	0.40	0.46	0.31	0.56	0.966	1.000
FHP–U6 (mm)	0.56	0.59	−2.13	0.97	−0.15	*0.008*	0.335
FHP–U1 (mm)	1.32	−0.40	−2.64	0.07	−0.04	**0.002**	0.104
FHP–L6 (mm)	5.40	4.19	2.03	5.29	3.57	*0.006*	0.285
FHP–L1 (mm)	5.16	4.22	1.68	5.32	4.41	*0.012*	0.473
Co–A (mm)	1.88	1.30	0.40	1.11	0.60	0.546	1.000
A–FHP (mm)	1.07	0.64	−0.54	1.72	−0.21	0.056	1.000
Ar–Go (mm)	4.08	3.82	2.03	3.25	1.82	*0.023*	0.887
Co–Gn (mm)	6.16	5.83	4.30	4.53	3.60	0.246	1.000
B–FHP (mm)	3.82	2.81	1.34	4.02	1.23	0.067	1.000
Go–Me (mm)	2.57	2.53	1.80	2.05	2.20	0.763	1.000
Pog–FHP (mm)	4.07	2.94	1.37	3.74	1.21	0.123	1.000
Go–FHP (mm)	−0.38	−0.44	1.64	−0.49	1.46	0.514	1.000
Go–Pog (mm)	2.37	2.30	1.70	2.26	2.60	0.874	1.000
SN^ANSPNS (°)	−0.04	−0.10	−0.20	0.68	0.00	0.672	1.000
SN^GoMe (°)	−0.63	−0.53	0.85	−0.11	0.40	0.070	1.000
ArGo^GoMe (°)	0.80	1.00	0.35	0.89	−0.40	0.759	1.000
SNA (°)	−0.31	0.07	−1.20	−0.21	−1.20	0.075	1.000
SNB (°)	1.76	1.93	0.40	1.32	0.40	**0.003**	0.128
ANB (°)	−2.12	−1.83	−1.65	−1.37	−1.60	0.333	1.000
OJ (mm)	−4.27	−5.22	−4.86	−5.26	−4.16	0.349	1.000
Wits	−2.91	−2.62	−2.21	−1.72	−2.56	0.487	1.000
S–Go (mm)	4.61	3.77	2.90	3.84	2.40	0.058	1.000
N–Pog (mm)	4.73	4.24	4.12	4.58	3.16	0.784	1.000
N–Me (mm)	4.63	4.27	4.50	4.53	3.20	0.889	1.000
ANS–Me (mm)	2.67	2.76	3.12	1.96	2.54	0.702	1.000
N–A (mm)	1.58	1.03	1.26	2.25	0.36	0.251	1.000
N–B (mm)	4.57	3.80	4.53	4.59	2.58	0.566	1.000
N–ANS (mm)	1.29	0.92	0.91	2.02	0.54	0.273	1.000
N′Ns ′^Ns′Pog′ (°)	0.76	1.00	0.65	1.37	1.20	0.931	1.000
N′Sn ′^Sn′Pog ′ (°)	2.90	3.07	2.55	3.37	2.20	0.938	1.000
NLA (°)	−0.88	0.27	1.85	−0.84	0.20	0.633	1.000
FHP–upper lip (mm)	1.90	0.91	−0.97	1.73	−0.13	*0.039*	1.000
FHP–lower lip (mm)	4.10	2.84	0.32	4.77	2.04	**0.002**	0.116
Upper lip–E line (mm)	−2.20	−2.33	−2.65	−1.89	−2.00	0.611	1.000
Lower lip–E line (mm)	−0.45	−0.80	−1.35	0.21	0.60	*0.032*	1.000
Sn′–Me′ (mm)	2.63	3.00	2.30	2.26	2.20	0.931	1.000

out by postgraduates in training. Also important to highlight is the fact that the lateral cephalometric radiograph at T2 was used to be taken after completing fixed appliances treatment. Therefore, proclination of the lower front teeth was actually diagnosed after the appliances were already removed.

Another remarkable finding was the mesialisation of the lower molar both at T1 and T2. Possible explanations for this phenomenon include the leeway space completion and the use of Class II elastics, consuming space from anteriorly derotated teeth and increasing labial inclination of lower front teeth during alignment.

Skeletal changes were particularly seen in the dimensions of the mandible. These increases in size were twice as big at T1 compared with the increases at T2. More interestingly, these significant increases after functional treatment were obtained after one-third of the total treatment time: the time interval between T0 and T1 was 11.1 months and between T1 and T2 was 21.8 months. Since the amount of growth seen in interval T1–T2 can be considered as normal growth, we would argue that jumping the bite with a functional appliance has some favorable growth effect on the dimensions of the mandible. Subcategorizing the results according to the initial growth pattern was done because in literature, the use of functional appliances is often discouraged for correcting a Class II relationship in an open growth pattern patient. In theory, this would open the bite and elongate the face even more (50,51). However, our results suggest that a functional appliance can be used in open growth pattern patients, because no differences in facial height were found between the different growth pattern groups at any time point.

The soft tissue analysis showed that functional appliances tended to decrease the profile convexity. Also, the lower lip showed more protrusion, which is in agreement with other studies (42,43). Our data also revealed a retrusive position of the upper and lower lip towards the esthetic line, both after functional and fixed appliances. This seemed logic for what concerns the upper lip after functional treatment, when we noticed retroclination of the upper incisors. For the lower lip, it seemed somewhat contradictory because protrusion was seen after functional treatment. An explanation could be found in the fact that the esthetic line changes as a result of advancement of the mandible. Also growth of the nose has an influence on this reference line. These factors could result in a retrusive position of the lip (43). At T2, the lower anterior soft tissue facial height increased a little bit more, which was probably due to natural growth.

In the present study, no significant correlations could be found between the obtained results and gender, CVMS, chronological age, and dental age. A difference in the amount of mandibular growth and different treatment responses to functional appliances is reported in literature for both genders (29,52,53), but in many studies, there is incomplete reporting of separate data for boys and girls, and therefore, these statements should be formally assessed (27). Our results also suggest that the higher the CVMS at T0, the smaller some skeletal treatment results at T2 were. Since the reproducibility of the CVMS has been questioned recently, the validity of this method should be interpreted cautiously (54). For this reason, we also determined the dental age according to Willems *et al.* (46), finding no differences in treatment results depending on the dental age at T0. This is in agreement with the results of the systematic review of Koretsi *et al.* (36). When we compared the results for the different functional appliances used, these could be split into two groups. The first one—including the Andresen, (Half-)Open activator, and Bionator—affected mainly the lower jaw, especially by eversion of the lower front teeth and with a smaller effect on the upper jaw. The second group (Van Beek activator) had more effect on the upper jaw by constricting its growth. Also the effect on the upper incisors was more pronounced compared with the first group. We saw more retroclination of the upper incisors and a significant retroclination of the upper molar. The reduction of the SNA angle was bigger, and the increase of the SNB angle was smaller. Less proclination of the lower front teeth was seen compared with the other group. Nevertheless, after the multiple testing correction, no significant differences between the appliances were observed, and no superior results were found for any of them, suggesting that they can all be successfully used when treating a Class II relationship. Choosing an appliance will thus rather depend on the position of the incisors at T0. For example, a Half-Open activator that contains a bumper spring will be more useful in a Class II, 2 patient with retroclination of the upper incisors, while a Van Beek in cases with Class II, 1 time and strong labial inclination of the upper incisors can be used.

Conclusion

An improvement of the Class II relationship was observed after functional treatment, mostly due to dentoalveolar changes: correction of the upper incisor position and proclination of the lower front teeth. Changes in the skeletal structures were also noticed: there was a constriction of the maxillary growth combined with a more protruded position of the mandible. The increase in skeletal size of the mandible at T1 was significantly larger compared with the increases at T2, while time interval T0–T1 was twice as short as T1–T2. After fixed appliances no further proclination of the lower incisor was noticed and the upper incisor remained approximately at the same position. Functional treatment should not be directly excluded for open growth pattern patients and for patients with initial high labial inclination of the lower incisors.

Conflict of interest

None declared.

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